AIRCRAFT PHASED ARRAY ANTENNA STRUCTURE INCLUDING ADJACENTLY SUPPORTED EQUIPMENT

FIELD OF THE INVENTION

[0001] The present invention relates generally to aircraft antenna systems and more specifically to a phased array antenna system having both phased array antenna elements and antenna support equipment mounted within the antenna structure.

BACKGROUND OF THE INVENTION

[0002] Aircraft utilize antenna and associated antenna support equipment to transmit, receive and download data communication signals. Aircraft antenna(s) are typically surface mounted on the outer fuselage of the aircraft. Aerodynamic drag concerns require the antenna(s) be shaped to reduce drag on the aircraft. Associated equipment is normally located inside the aircraft on support structures developed for this purpose.

[0003] When new systems or technologies are developed or additional communication system equipment is required on an aircraft, additional space must normally be found inside the aircraft for the associated support equipment. On commercial aircraft in particular, space is often created for this equipment in the overhead compartments, and in particular, over the walkways (i.e., central or side aisle-ways) of the aircraft. The drawback of using this space is its constraint on overhead height in the aircraft walkways.

[0004] Another problem exists on current aircraft that employ phased array communication antennas. Most currently employed phased array antennas operate at low voltage, i.e., three to six volts direct current (DC). This low voltage requires a correspondingly high current to operate the antenna system. Drawbacks to carrying high current include increased cabling weight between the antennas and their power transformers, and power loss due to heat generation and subsequent transmission loss. In an exemplary application currents as high as about 90 amperes must be carried. A 90 ampere current rating requires a cable size of about four gauge, American Wire Gauge (AWG) be used. Even with this size wire, however, cable heat and power loss places a practical limit on the distance between the power supply and the antennas to about 3.1 to 4.6 meters (10 to15 feet). This constrains the location of the antenna and/or the location of the aircraft mounted antenna support equipment.

[0005] The above problems are compounded for aircraft required to communicate via signals from satellite communication systems. These systems utilize radio frequency (RF) signals in the Ku-band frequency range, for example in the 12 to 14 gigahertz (GHz) range. RF signals on the transmit channel are normally about 14 GHz and above (up to about 44 GHz) and RF signals on the receive channel are normally about 12 GHz and above (up to about 20 GHz). In this frequency range attenuation of signal strength becomes a critical drawback as the antenna/antenna equipment and aircraft communication equipment are separated. As an exemplary loss in the RF frequency range, about every three feet of signal line length used between the antenna and down-converting

equipment results in approximately 50% loss in signal strength. As a practical result, an exemplary limit now applied to control this attenuation provides that down-converters be separated by a distance of no greater than about 1.2 meters (four feet) from their respective antenna(s). This places a greater constraint on the location of both the antenna(s) and antenna support equipment than the above noted constraint due to power loss.

[0006] Further problems are created for aircraft when new communication systems, such as Connexion By Boeing^{SM}, require one or more new antennas be installed. In the exemplary Connexion By Boeing^{SM} system, the antennas are an intermediary subsystem between the aircraft and the ground. To incorporate the Connexion By Boeing^{SM} system onboard an aircraft, two phased array antennas are required, and the associated support equipment for the phased array antennas, if stored within the aircraft, occupies about six boxes. In an example case of a narrow body aircraft (i.e., an aircraft having a single aisle), providing space to locate and mount eight boxes requires using space over the aircraft aisle-way. The drawback to this as noted above is reduced height along the center aisle-way of the narrow body aircraft. Wide body aircraft (i.e., two or more aisles) are constrained by addition of six boxes, but not to the same degree as narrow body aircraft.

[0007] It is aerodynamically desirable to place an antenna at the top of the aircraft fuselage along a vertical plane perpendicularly intersecting the aircraft's longitudinal axis near the leading edge of the aircraft wings. This preferred antenna location, together with the above equipment and cable length

constraints, further constrains the arrangement. In an alternate arrangement, sets of antennas are provided. Multiple arrangements are possible. Two exemplary arrangements are a first fore-aft arrangement comprising two antennas and a second side-by-side arrangement of preferably four antennas. With the side-by-side arrangement, two antennas are preferably located on each side of the aircraft, to improve the field of view toward the horizon (also called a "saddlebag" configuration). Both saddlebag and fore-aft arrangement antenna configurations improve the arrangement of support equipment by spreading out the equipment, but still constrain the overall arrangement if the support equipment is all located within the aircraft.

SUMMARY OF THE INVENTION

[0008] In addition to the advantages noted herein, the above goals are achieved and the above noted drawbacks and limitations for aircraft communication systems are overcome by the antenna system of the present invention.

[0009] In one aspect of the present invention, a phased array antenna system for a mobile platform is provided. The system comprises the following. A transmit antenna is disposed within a transmit antenna housing and a receive antenna is disposed within a receive antenna housing. The receive antenna operates to receive a receive antenna signal and converts the receive antenna signal to an aircraft communication frequency signal before outputting the receive antenna signal from the receive antenna housing. The transmit antenna operates

to transmit a transmit antenna signal and converts the aircraft communication frequency signal into the transmit antenna signal within the transmit antenna housing.

[0010] In another aspect of the invention, a phased array antenna communication system for external mounting on a mobile platform is provided. The system comprises the following. A pair of antennas are provided. One of the antennas is a transmit antenna and one is a receive antenna. At least one antenna housing is provided for the transmit antenna and the receive antenna. Each antenna housing has either a transmit antenna equipment group or a receive antenna equipment group. The equipment group electrically communicates with an onboard aircraft communication signal. The onboard communication signal has an operating frequency ranging from an ultra-high frequency to an L-band frequency. An aircraft mounted converter converts an aircraft service voltage to an antenna power transfer voltage. Each antenna housing has a transfer converter to convert the transfer voltage to an antenna operating voltage for local use in the antenna.

[0011] In a further aspect of the invention, an aircraft phased array antenna communication system is provided having antennas and antenna servicing equipment in at least one aircraft mounted structure. The system comprises the following. At least two antenna discs are externally mounted on an aircraft fuselage. Each disc is either a transmit antenna or a receive antenna. The transmit antenna and the receive antenna each have a plurality of phased array antenna elements. Each antenna element of the transmit antenna and the

receive antenna are joined to a surface of a pre-selected antenna disc to either transmit or receive an electromagnetic signal. The electromagnetic signal has a transmit frequency and a receive frequency. A power and control equipment group is coupled to each disc, which converts between an aircraft communication frequency and either the receive or transmit frequency. The disc is shaped to incorporate the antennas and the equipment group within an aerodynamic configuration.

[0012] In still another aspect of the invention, signal attenuation is reduced. Signals at or above S-band frequency (about 6 GHz) including the exemplary Connexion By Boeing[SM] signal frequency in the 12 to 14 GHz range, suffer attenuation of signal strength over relatively short, i.e., about 3 meters (3.25 feet) or less cable lengths. According to the invention, upon receipt of a signal above S-band frequency by a phased array receive antenna, a conversion is performed within the antenna structure down to an L-band frequency range which is within the aircraft communication frequency. For the exemplary Connexion By Boeing[SM] system, a 12 GHz receive channel signal is reduced to an L-band frequency of about one (1) GHz. The 1 GHz frequency is used when transferring communication signals within the aircraft. Converting to the L-band 1 GHz frequency results in signal attenuation which is about 10% of the attenuation at the higher 12 GHz frequency.

[0013] For signal transmission, the 1 GHz internal signal frequency is transferred to a transmit antenna where it is converted within the antenna to the 14 GHz RF transmit frequency. The converters required to convert each of the

receive and transmit signals between the higher receive and transmit ranges and the lower L-band frequency range are incorporated within the antenna structure mounted external to the aircraft. In addition to reduced attenuation, this conversion unconstrains the exemplary RF frequency limitation of about 1.2 meters (four feet) for signal line length between the antenna(s) and converter(s) by increasing this distance up to about 62 meters (two hundred feet).

[0014] Further areas of applicability of the present invention will become apparent from the detailed description provided hereinafter. It should be understood that the detailed description and specific examples, while indicating the preferred embodiment of the invention, are intended for purposes of illustration only and are not intended to limit the scope of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0015] The present invention will become more fully understood from the detailed description and the accompanying drawings, wherein:

[0016] Figure 1 is a perspective view of an exemplary aircraft having two phased array antenna structures of the present invention mounted on the fuselage;

[0017] Figure 2 is a perspective view of an exemplary tear-drop shaped phased array antenna of the present invention showing an antenna and support equipment space envelope;

[0018] Figure 3 is a block diagram of the present invention showing a receive antenna connected to the system power and control unit; and

[0019] Figure 4 is a block diagram of the present invention showing a transmit and a receive antenna connected to the system power and control unit.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0020] Figure 1 provides transmit and receive antennas for one aspect of the present invention. An exemplary aircraft **2** is shown having an exemplary arrangement of two antennas, a transmit antenna **4** and a receive antenna **6** mounted on the outer aircraft fuselage **8**. In a preferred embodiment both the external configurations of the transmit antenna **4** and receive antenna **6** have a tear-drop shape to minimize aerodynamic drag on the aircraft. The preferred location for the transmit and receive antennas is in a fore-aft, linear arrangement having both antennas located in parallel with a longitudinal axis **L** of the aircraft on an upper surface of the fuselage **8** and proximate to the fore-aft location along the longitudinal axis **L** where the leading edge of the aircraft wings **10** intersect the aircraft **2**. The one or more antennas of the present invention are mounted directly to the outer fuselage **8** of the aircraft.

[0021] Referring now to Figure 2, a tear-drop shaped antenna configuration for mounting the array electronics and the electronics module for an antenna of the present invention is shown. Figure 2 represents an exemplary tear-drop shaped antenna body **12** wherein either the transmit antenna **4** elements or receive antenna **6** elements may be configured within an exemplary circular array electronic space envelope **14** shown. An antenna body **12** having a generally tear-drop shape advantageously provides space for both the array

electronics space envelope **14** and the electronics module space envelope **16**. Electronics module space envelope **16** represents the mounting space envelope for associated antenna support equipment located in either antenna structure. Also provided on the antenna body **12** are access openings for the mounting bolts (not shown) which support the antenna body **12** to the fuselage **8** of the aircraft. Access areas **18** are shown for an exemplary 6 mounting bolt configuration.

[0022] Antenna body **12** further comprises an antenna trailing edge **20** and an antenna leading edge **22**. Electronics module space envelope **16** is outlined on the antenna upper surface **24** of antenna body **12.** The exemplary antenna body shown has an antenna depth A, an antenna length B and an antenna width C. In a preferred embodiment of the invention, the antenna depth A is about 5 centimeters (2 inches) at its minimum depth which occurs at about the center of antenna body **12**. The antenna length B is up to about 1.8 meters (72 inches) and the antenna width C is about 1.1 meters (42 inches). Dimensions A, B, and C for the antenna body can also be varied depending upon the shape and size of the array desired for the phased array antenna elements **26** provided in the array electronics space envelope **14**.

[0023] In the configuration of Figure 2, exemplary electronics space envelope **14** is circular in shape, however the shape of the envelope can be varied to suit the configuration of the phased array elements **26**. Only a portion of the phased array elements **26** are shown for information. The number of elements can easily exceed one thousand in a typical phased array antenna.

[0024] By providing a 5-volt DC converter (not shown) in close proximity to phased array elements **26** and within the electronics module space envelope **16** of the antenna, the size of the cabling (not shown) required to carry the large current between the 5-volt DC converter and the individual elements is reduced. The cable which is normally used for the purpose of carrying high current between the 5-volt DC converter and the phased array elements can be replaced with a solid bus bar for an antenna of the present invention.

[0025] The plurality of phased array elements **26** comprise multiple replications of phased array antennas which may be populated (i.e., configured) into a grid pattern depending upon the pre-determined shape. In addition to the circular shape shown, the phased array elements may be populated in rectangular, elliptical, or other geometric shapes. The antenna depth A shown in Figure 2 is largely dependent on the space envelope required for the individual phased array elements. Support equipment for the antenna array(s) is advantageously located adjacent to the phased array elements without increasing antenna depth A.

[0026] Referring to both Figures 3 and 4, block diagrams of the components and connections of the present invention are shown. Each array comprising multiple phased array antenna elements is normally sub-divided into one or more sub-arrays. Figure 3 provides an exemplary four sub-arrays; sub-arrays **50**, **52**, **54**, and **56**. Each sub-array is supported by an external beam steering controller. External beam steering controller (EBSC) **58** supports sub-

array **50**, EBSC **60** supports sub-array **52**, EBSC **62** supports sub- array **54** and EBSC **64** supports sub array **56**.

[0027] Also provided within the structure of receive antenna **6** is a down converter unit **66**. The combined signals from each of the individual sub-arrays is transferred to down convert unit **66** after being combined by signal combiners **68**. A radio frequency (RF) monitor **70**, linear polarization (Lin/Pol) converter **72** and radio frequency converter assembly (RFCA) **74** are also provided. In an alternate embodiment, the linear polarization converter **72** could be placed ahead of down converters **66**. The combined signals are converted from the about 12 GHz receive frequency to an L-band frequency range. In a preferred embodiment the signals are converted to a frequency of about 1 GHz. The 1 GHz signal frequency is then transmitted to internal aircraft communication systems equipment (not shown) via the receiver/transmitter system (in phantom). Multiple, concurrent L-band changes can be provided to account for polarization-diversity of satellites at a single orbital location. In the preferred embodiment, up to four concurrent channels are provided to the receivers, representing vertical, horizontal, left-hand circular, and right-hand circular polarizations. Receive antenna **6** also employs a power converter **76**, and a power monitor and control unit **78**. Power converter **76** converts the higher DC voltage from the aircraft system power control unit **80** to the lower 3 to 6-volt DC power required by the antenna array.

[0028] Figure 3 identifies the DC power provided between system power and control unit **80** and power converter **76** delivered at 270 volts DC, then

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delivered differentially at +/- 135 volts DC required to operate each of the receive antenna **6** and the transmit antenna **4**. For the antennas of the present invention, DC power may range from the preferred high of about +/- 135 volts to each antenna to a low of about 28 volts to each antenna. The higher voltage minimizes current and associated cable weight. The differential voltage of +/- 135 volts DC referenced to aircraft structure reduces corona effects compared with 270 volts DC referenced to aircraft structure. The components within receive antenna **6** are supported by the antenna structure to the fuselage of the aircraft. The remaining items shown on Figure 3 are supported within the aircraft, comprising system and power control unit **80** and its necessary components.

[0029] System power and control unit **80** comprises a power conversion unit **82**, a power monitor unit **84**, a system control unit **86**, and an internal power source **88**. Power conversion unit **82** receives the aircraft three-phase 115-volt AC, 400 Hz power source and converts this to the 28 to 270 volt DC power for powering the phased array antenna elements. The output of power conversion unit **82** supplies internal power unit **88** and power monitor and control unit **84**. The direct current voltage which is provided to each antenna element array is provided through power monitor and control unit **84**. The output of internal power unit **88** provides additional power to power monitor and control unit **84** as well as power to system control unit **86**. System control unit **86** provides steering commands to manage the configuration of the arrays of the two antennas **4** and **6** respectively. System control unit **86** is shown interfacing with a receiver/transmitter (shown in phantom). The receiver/transmitter is an internal

aircraft mounted component which is used to convert digital signals into the L-band frequency for internal aircraft use. The receiver/transmitter is shown in phantom for information purposes only.

[0030] Referring now to Figure 4, a transmit antenna of the present invention is shown. Similar to the arrangement of Figure 3, Figure 4 identifies the system power and control unit. This unit is the same unit identified in Figure 3 and therefore no further description of its components will be provided herein. Transmit antenna **4** is comprised of a group of components which will be further described herein. Power converter **90** is similar to power converter **76** of Figure 3 in that power converter **90** is used to convert the +/-135-volt DC power to the antenna 3 to 6-volt DC power. Power monitor and control unit **92** is similar to power monitor and control unit **78** shown in Figure 3. Output from the power converter **90** and power monitor and control unit **92** is provided to the sub-arrays of antennas similar to Figure 3. An Up-converter **94** and an Up-converter RF power control unit **96** are also shown. These units receive a signal from system control unit **86** and convert the L-band, 1 GHz signal from the aircraft communication systems via the receive/transmit system (in phantom), up to the 14 GHz transmit frequency required for the exemplary Connexion By Boeing^{SM} System. The output of Up-converter **94** supplies the input to power amplifier **100**, power amplifier **102**, power amplifier **104**, and power amplifier **106** respectively. In an alternate embodiment, a single power amplifier supplies all four sub-arrays, depending on specific RF power requirements.

[0031] Figure 4, similar to Figure 3 provides an antenna arrangement having four sub-arrays of phased array antennas. The phased array antennas are shown as individual sub-arrays **116**, **118**, **120**, and **122** respectively. Each of the sub-arrays of antennas are consequently controlled by external beam steering controllers (EBSCs) **108**, **110**, **112**, and **114** respectively. Power amplifiers **100**, **102**, **104**, and **106** boost the signal strength prior to transmission through the phased array antenna elements. The output of each individual power amplifier provides a respective sub-array of phased array antenna elements. A radio frequency monitor **98** is also connected to the Up-converter, RF power control unit, providing a measurement of transmitted power.

[0032] The present invention provides several advantages. By advantageously using the volume of externally mounted antenna structures, support equipment for the phased array antennas is positioned within the antenna structure. This permits the internal arrangement of the aircraft to be unconstrained by the storage requirements for these pieces of equipment. By converting from the aircraft generated 3-phase AC power to an intermediate or transfer power, the size and weight of cabling between the aircraft mounted converters and the antenna mounted converters reduces weight and unconstrains the arrangement within the aircraft for this cabling. By locally converting an antenna transfer power within each antenna structure to the 3 to 6 volt DC voltage required to operate the elements of the phased array antennas, the size and amount of cabling required between these converters and the individual sub-arrays of elements can be controlled and weight therefore

reduced. By converting to a lower internal aircraft communication frequency than the frequencies transmitted and received by the antennas, and locating the frequency converters within the antenna structures, signal attenuation loss is reduced.

[0033] The description of the invention is merely exemplary in nature and, thus, variations that do not depart from the gist of the invention are intended to be within the scope of the invention. Such variations are not to be regarded as a departure from the spirit and scope of the invention.